Spectrum Analyzer for VHF/UHF Amateurs Constructing a Home-Made Universal HF-Module

by E. Berberich, DL 8 ZX

The description of the first spectrum analyzer at the VHF-UHF Convention 1976 in Munich, and in VHF COMMUNICATIONS led to a large number of letters from amateurs that wished to construct such a spectrum analyzer. Unfortunately, the construction difficulties with respect to the RF-input module, and the small frequency range of the first version were not really able to satisfy the demands that were placed on it. The development and construction of a suitable RF-input module is extremely difficult for radio amateurs that do not have access to a large amount of expensive measuring equipment (QRL). For this reason, a new conception was developed that can be realized using conventional modules and components. This new design was described at the VHF-UHF Convention 1980 in Munich and is now to be described in this article.

1. METHOD OF REALIZING THIS AIM

In order to display a wide frequency range at one time, it is necessary to use a high first intermediate frequency (IF) and an oscillator that can be swept electronically over a correspondingly wide range. There are several possibilities of avoiding construction of these critical modules.

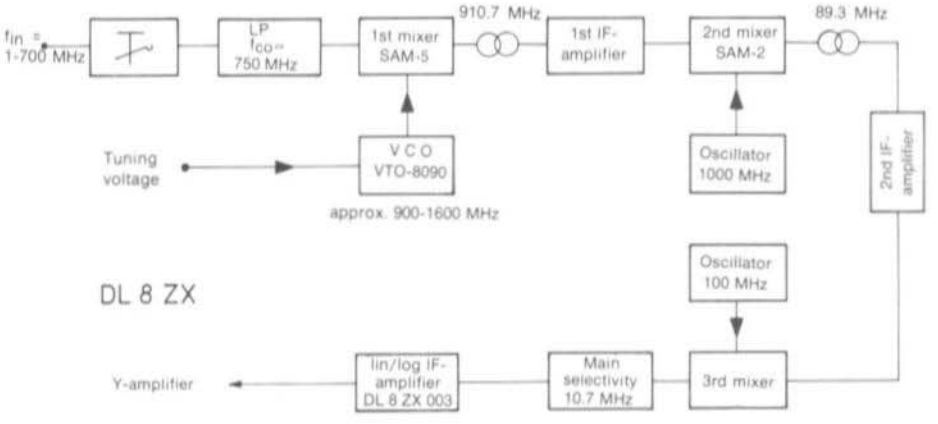

Fig. 1: A spectrum analyzer using professional RF-components

1.1. Use of Industrial RF-Modules

Complete ring mixers for 50 Ω are available on the market that can be used up to very high frequencies. VCO-modules are also available for the VHF to SHF range. The required high-pass and low-pass filters, as well as calibrated attenuators are also available from well-known companies. **Fig.1** shows the use of such components in conjunction with a spectrum analyzer (S.A.). The only, but important disadvantage is the price of these modules, which is usually far more than is available for one's hobby.

1.2. Use of a Cable-TV-Tuner

Special tuners are manufactured for cable television (CATV) that can be tuned continuously from 40 to 300 MHz and operate with a first IF of 600 MHz. CATV-tuners also have good large-signal handling capabilities.

Figure 2 gives the block diagram of a spectrum analyzer using a CATV-Tuner. This SA can cover the frequency range of 0.1 to 40 MHz, and 40 to 300 MHz in two switchable bands. However, it is not easy to obtain such tuners from the service department of the TV-manufacturers, or CATV-companies; presumably, because they think one wishes to tap into their cable system without paying the monthly fees ! For this reason, the author attempted to find a further solution to the problem.

1.3. UHF-TV-Tuner as Tunable First IF-Amplifier

A spectrum analyzer can also be realized using a UHF-tuner from a TV-receiver. Since it is to be used in a measuring system having a high dynamic range, a TV-tuner should be found having large-signal handling capabilities, that does not use a self-excited mixer. A further advantage would be a tunable input circuit and a 75 Ω IF-output.

As far as the author knows, no separate UHF-tuner is manufactured in Germany, but he found a suitable tuner in a Japanese TV-receiver. This used a UHF-tuner using metal-plate chambers with tunable input stage, as well as possessing a separate oscillator and diode mixer. This tuner is readily available in Germany from the service departments of the largest mail-order company.

For those readers that are not able to obtain such a tuner, it is possible that this could be obtained for you in Germany at low cost.

Figure 3 shows the final solution in the form of a block diagram. In order to avoid expensive coaxial switches, each frequency band possesses its own input connector. The range switching is made at the input of the tuner with the aid of PIN-diodes. In order to obtain a constant sensitivity over the whole tuning range, the tuner must have a slightly sloping frequency response.

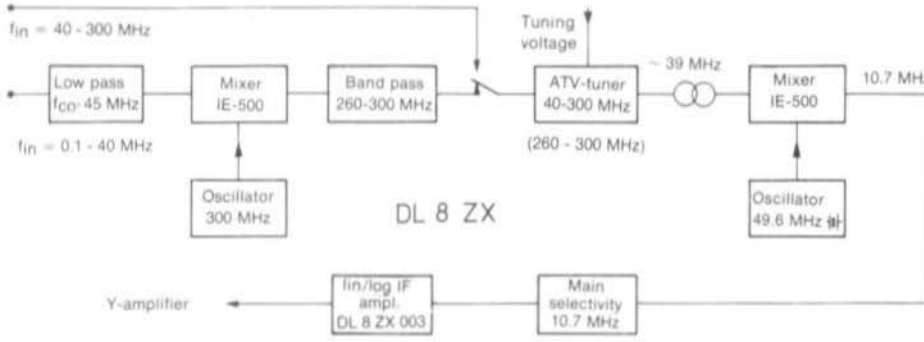

Fig. 2: An amateur spectrum analyzer using a CATV-tuner as tunable 1st IF-amplifier

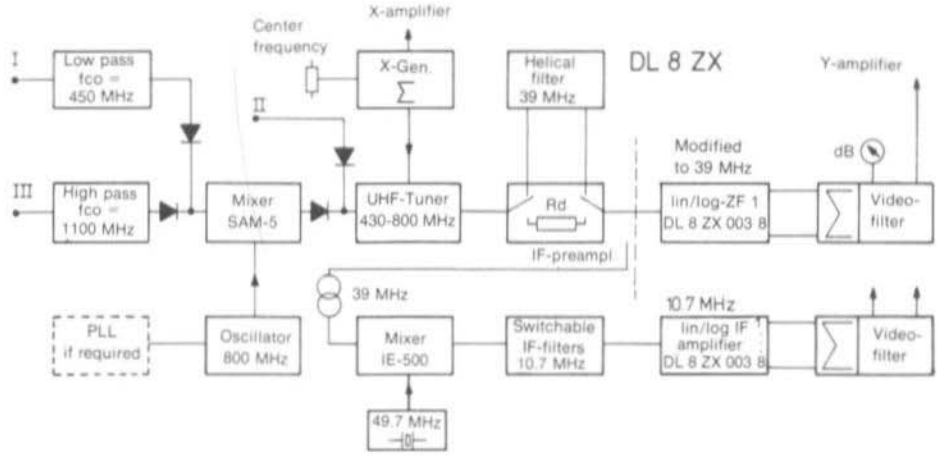

Fig. 3: The final design using a TV-UHF-tuner in the 1st IF

The measuring accuracy is mainly determined by this characteristic.

As can be seen in the block diagram, three frequency ranges of approximately 400 MHz each are obtained in a simple manner: A lower band from approximately 1 MHz (lower cut-off frequency of the mixer used) to 400 MHz (I), the direct tuning range of the tuner from approximately 430 to 800 MHz (II), and finally an upper band (III), representing the image frequency of the lower band, which covers from 1230 to 1600 MHz.

Of course, all UHF-SHF-constructors will have noticed that the most important frequency range in the order of 1150 MHz, which is used as local-oscillator frequency for virtually all microwave amateur bands, is not covered. For this reason, the 800 MHz oscillator is designed to be tunable from 710 to 800 MHz. This means that it is possible to shift the frequency range somewhat when the mixer is used (premix-operation). This first local oscillator could be locked to a 72 MHz crystal oscillator using a PLL-circuit in conjunction with a switchable divider (by ten or by eleven). If narrow-

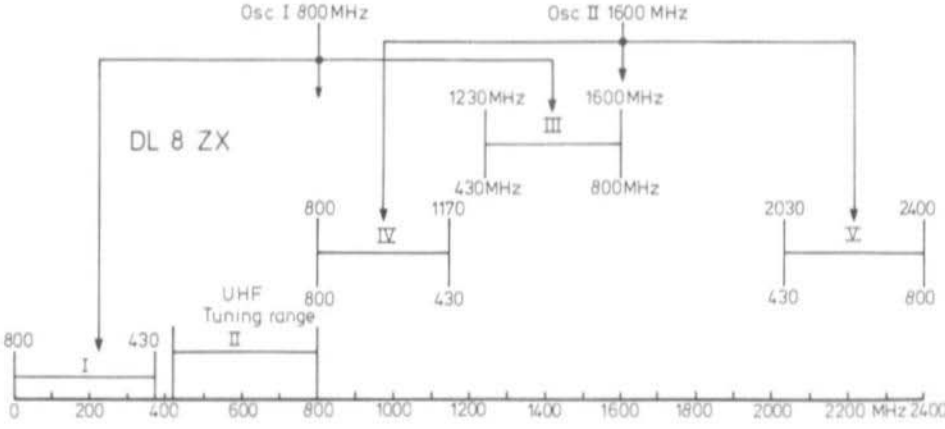

Fig. 4: Frequency plan for the final spectrum analyzer shown in Fig. 3

band filters are used in the first IF, these measures are absolutely necessary for suppressing the interference deviation.

Figure 4 shows a frequency plan which allows two further frequency ranges to be obtained using a second local oscillator. These ranges (IV) and (V) have still not been realized by the author.

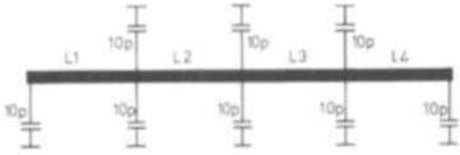

Fig. 5:
A low-pass filter for range I
L 1 - L 4: each 35 mm long, 100 Ω stripline manufactured by Minimount

2. THE FINAL CIRCUIT

As has already been mentioned, the spectrum is to be constructed as given in Fig. 3. Further details are now to be given regarding various modules.

2.1. Input Low-pass Filter for Range I

The low-pass filter for 450 MHz is constructed in a metal-plate case of 37 mm x 111 mm. The inductances **(Figure 5)** consist of so-called Z-strips manufactured by Minimount. These self-adhesive epoxy-glass fibre strips with copper coating are available in approximately 100 mm length for the various impedances (50 Ω, 60 Ω, 75 Ω, and 100 Ω). Defined inductances can be manufactured using these strips and the following inductance values were calculated for the various stripline widths (impedances):

50 Ω: 3.9 nH;	60 Ω: 4.7 nH;
75 Ω: 5.8 nH;	100 Ω: 7.8 nH.

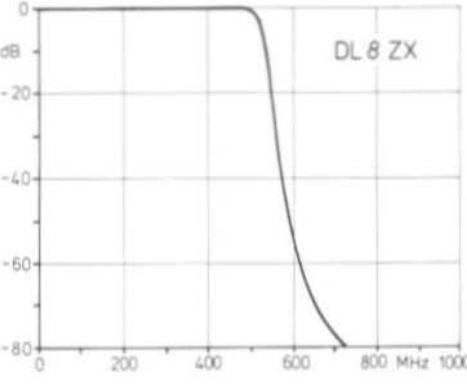

Fig. 6:
Characteristic of the low-pass filter given in Fig. 5

Of course, these values are only present when the striplines are glued to a metal surface. The 100 Ω line was selected for the low-pass filter in order to obtain the smallest possible construction. The measured attenuation curve is given in **Figure 6.**

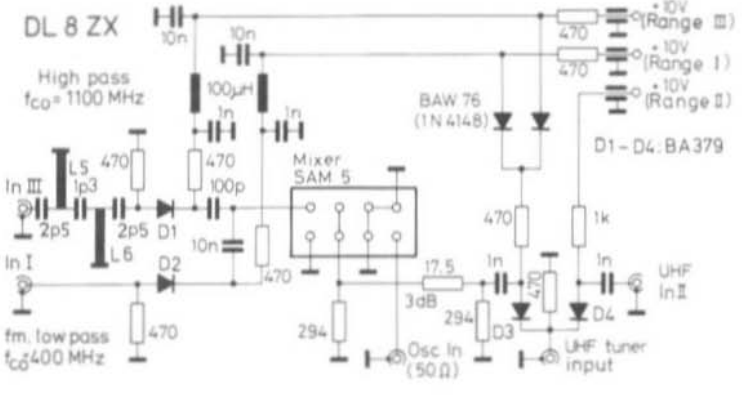

Fig. 7:
Premixer module with SHF high-pass filter and PIN-diode switch

2.2. 1100 MHz High-Pass Filter and Mixer

The SHF high-pass filter, PIN-diode switch, ring mixer, and a 3 dB attenuator for the IF-output are combined as shown in **Fig. 7** to form a »premixer« module. The high-pass inductances L 5 and L 6 have an inductance of 4 nH and have been constructed in printed technology.

The arrangement of the components is very critical in this module if the cross-talk between the three channels is to be kept to a low value. For this reason, a premixer-board was developed that may be described later.

2.3. Oscillator Module

The local oscillator frequency of 710 to 800 MHz is firstly generated in a free-running oscillator as shown in **Figure 8**. The resonant circuit inductance L 2 comprises a 3 cm long piece of 1.5 mm dia. silver-plated copper wire. A varactor diode type BB 105 is coupled to this line and used for tuning.

The oscillator drives into an aperiodic buffer with feedback, and a 3-stage low-pass filter. The filter is constructed in the same manner as the input low-pass filter for range I; inductances L 7, L 8, and L 9 are a single piece of 100 Ω stripline onto which the capacitors are soldered with a spacing of 17 mm each.

2.4. IF-Amplifier and Selectivity

The first IF of 39 MHz provided by the tuner is too low to obtain a high image rejection. For this reason, the dynamic range of the indicator was limited to 80 dB. This means that only 8 stages of the linear/logarithmic IF-amplifier DL 8 ZX 003 (VHF COMMUNICATIONS 2/1977) are used.

In the case of the author's prototype, the conversion to 10.7 MHz was not used in order to avoid unwanted reception points. When using an optimum construction, however, it is possible for double conversion to be realized satisfactorily in order to improve selectivity. The advantages of these measures were discussed in the previous publication, as well as in (3).

In the case of the author's prototype, only the selectivity of the 39 MHz-circuits is effective. The resulting overall bandwidth of approximately 600 kHz is too wide for narrow-band displays. Unfortunately, no commercially available crystal filters are known for a frequency of 39 MHz; crystal filters are available for 35.4 MHz / B = 8 kHz (Philips), 41 MHz / B = 7 kHz (Toyocom), but are too far from the required frequency of 39 MHz.

For this reason, the author calculated and constructed a helical bandpass filter for 39 MHz for the prototype system. Low-capacitance relays are used to switch this filter into the signal path when required (Fig. 3).

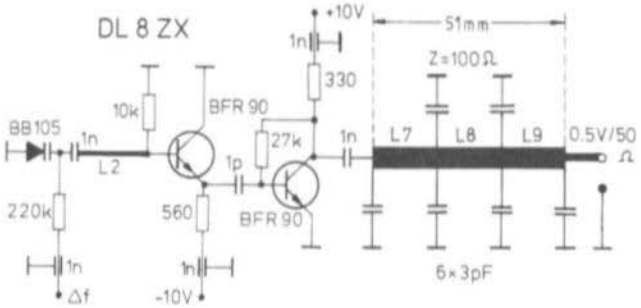

Fig. 8:
An 800 MHz VCO

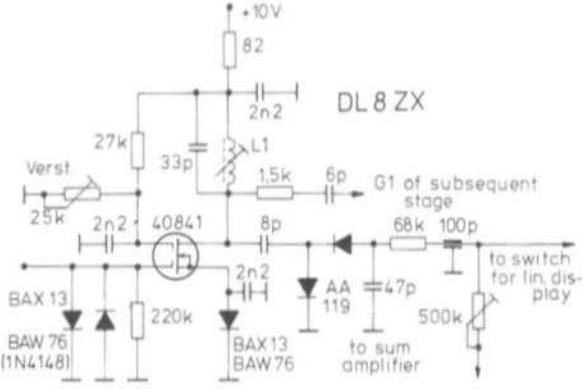

Fig. 9:
The IF-stages of module DL 8 ZX 003 are modified for 39 MHz

Fig. 9 shows one stage of the IF-amplifier DL 8 ZX 003 which has been modified for 39 MHz. Inductance L 1 consists of 11 turns of 0.4 mm dia. cotton-covered, enamelled copper wire, wound on a 4.3 mm coil former with violet core. If the inductances are enclosed in cans that are not too small, it is possible for the screening panels between the individual stages to be deleted.

A short description of the linear/logarithmic IF-amplifier is now to be given, since it forms the heart of the spectrum analyzer.

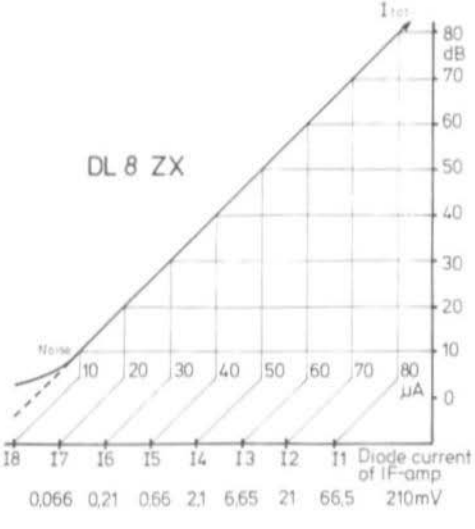

Fig. 10:
Development of the logarithmic scale

In order to obtain a dB-linear (in other words a logarithmic) scale over a large dynamic range, it is possible to use a so-called successive rectifier amplifier. It consists of several identical amplifier stages with a built-in rectifier. The amplifiers are connected in series and are adjusted for 10 dB per stage. A stage with an input impedance in the order of zero Ω adds the rectifier currents and passes them on to the Y-amplifier of an oscilloscope. **Figure 10** shows the development of the virtually ideal dB-linear scale.

A voltage-linear display is also possible and this is the reason for the designation: linear/logarithmic amplifier. This can be selected with switch S 1 **(Figure 11)** to find the amplifier stage 2 to 9 that is still operating in its linear range, according to the input level.

The impedance converter (LM 324) is followed by an active low-pass filter with variable bandwidth, equipped with a compensated operational amplifier type L 141 for stability reasons. A meter is also connected here for reading off the amplitude value of an individual spectral line, which is usually more accurate than when using an oscilloscope.

2.5. IF-Preamplifier

The diode mixer used in the UHF-tuner has quite a good large-signal handling capability, but exhibits a conversion loss. For

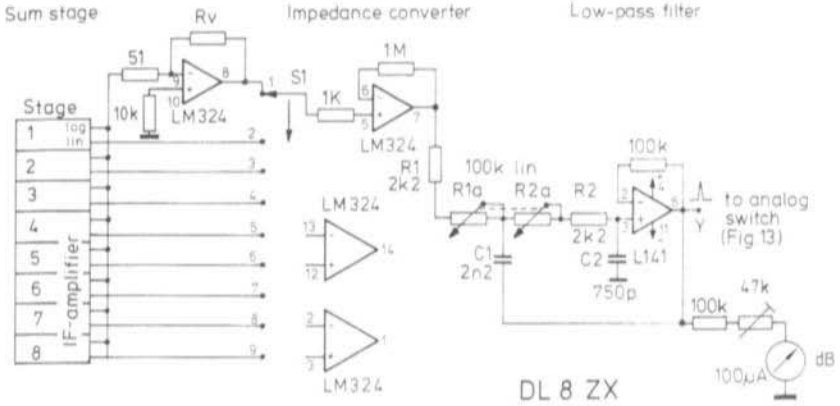

Fig. 11: Generation of the Y-signal and indicator circuit

this reason, a low-noise preamplifier as shown in **Figure 12** is connected in front of the linear/logarithmic IF-amplifier.

An additional filter can be connected at the output of this amplifier for improving selectivity. If the filter is bridged, resistor R_d is provided to compensate for the conversion loss of this filter in the passband range. In this manner it is possible to adjust the overall gain to be the same in every operating mode.

This circuit is also able to compensate for gain fluctuations during premix-operation by altering the G 2-voltage. Trimmer resistors are provided for this, which are switched with a further wafer of switch S 2. All inductances are wound on 4.3 mm dia. coil formers with violet cores.

2.6. Deflection Module

Since most oscilloscopes do not have an output for sawtooth voltage, the deflection voltage is generated in the spectrum analyzer. Specialists can thus use an additional possibility of equalizing the tuning voltage for frequency-linear display on the X-axis.

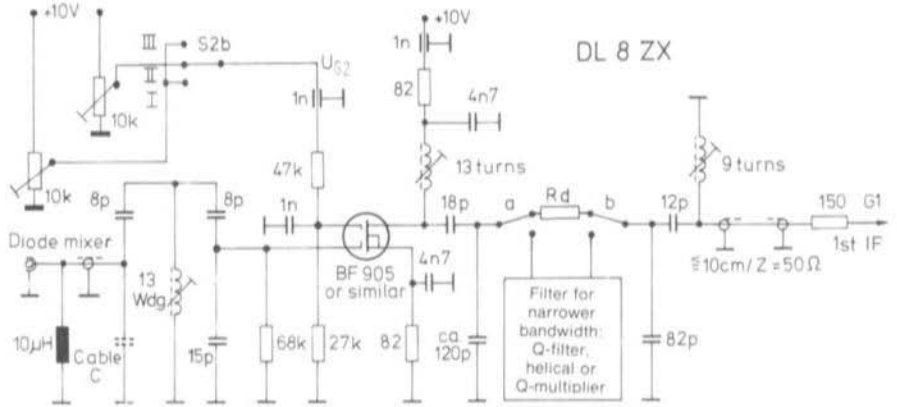

Fig. 12: IF-preamplifier for 39 MHz

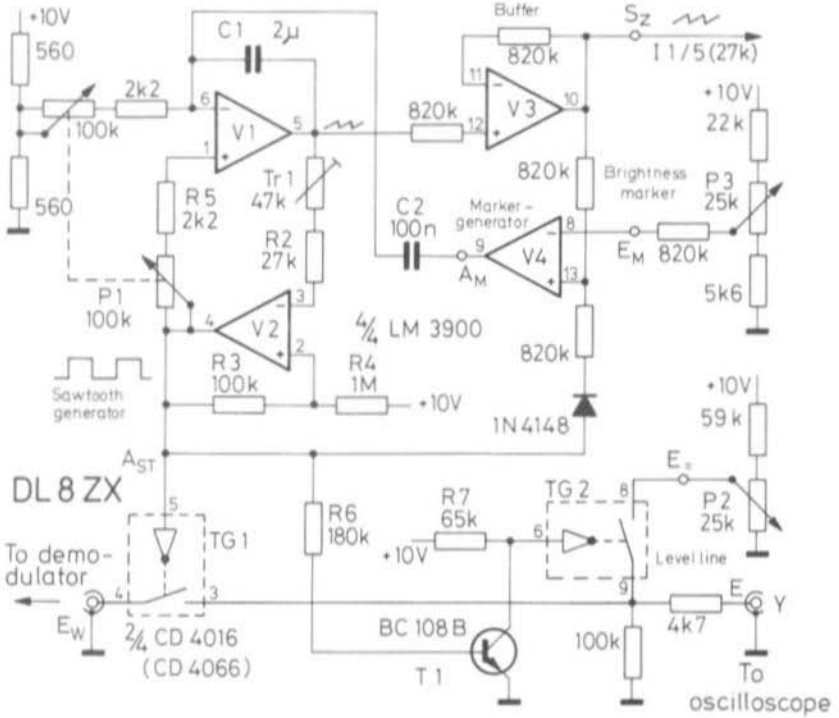

Fig. 13: Sawtooth generator for the X-deflection

The author used a deflection module as described in (2), that was modified so that the X-deflection frequency is continuously variable **(Figure 13)**. This is made with the tandem-potentiometer P 1. This adjustability is required for matching to the transcient behaviour of different IF-filters.

The deflection module also generates an Y-level line, as well as a brightness-marker on the X-axis. The oscilloscope used must, however, possess DC-coupled X and Y-amplifiers due to the slow processes present.

The description given in (2) described a suitable layout for this circuit.

The further processing of the X-deflection voltage, as well as the generation of the tuning voltage for the UHF-tuner is given in **Figure 14**. It should be mentioned that the tuning voltage must be extremely free of noise and hum voltages, since 60 mV will already cause a frequency shift of 1 MHz.

3. CONSTRUCTION DETAILS

All modules should be constructed in metal-plate cases, and all DC and audio-frequency voltages should be fed via feed-through capacitors in order to achieve that every module is RF-tight. All modules are then accommodated in a common metal case, whose dimensions are sufficiently large so that any interaction between the modules can be compensated for by changing the position of that module in the case. A large number of very strong transmitters (SW, VHF-broadcasting, TV) are to be found in this wide frequency range, and it is necessary to ensure that these are not introduced into the system. It is also necessary to provide a power-line filter, but this is only of advantage when the rest of the case is RF-tight.

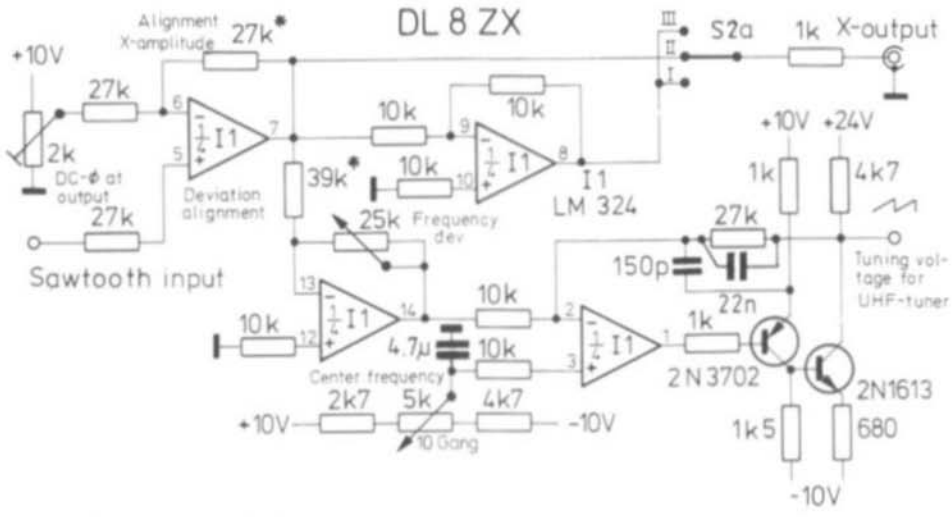

Fig. 14: Generation of the X-deflection and tuning voltage for the UHF-tuner

4. SENSITIVITY, CALIBRATION

The author's prototype was designed for a maximum input voltage of 30 mV for full-scale indication (frequency range II). The two premixer-ranges I and III exhibit an additional attenuation of approximately 10 dB, which limits the dynamic range to 70 dB. This loss was compensated for – within limits – by using an IF-preamplifier (see 2.5.) whose gain was variable. Fixed attenuator-links or a built-in calibrated attenuator can be used for attenuating higher input levels. Such attenuators are available commercially from approx. DM 350.—.

When the frequency deviation is switched off, it is possible to use the spectrum analyzer as measuring receiver; in this case, the VCO can be swept manually using a potentiometer. The built-in meter then indicates the level. Since the spectrum analyzer operates in a dB-linear manner, the meter will not require a special calibration.

The modulation of radio signals can be monitored using suitable demodulators connected to the IF-output.

Finally, it is possible to provide a frequency marker for the frequency axis, which is loosely coupled to the input. For instance, the calibration spectrum generator described by DC 6 HY would be suitable for this.

The spectrum analyzer could be extended by a number of further possibilities that allow this system to be extended to form a versatile and inexpensive measuring system for radio amateurs. Of course, it is not able to compete with expensive, professional analyzers.

The author and the publishers would like to hear your views on improving or simplifying construction, and on any additions that come to mind.

5. REFERENCES

(1) E. Berberich, DL 8 ZX: A Spectrum Analyzer for Amateur Applications VHF COMMUNICATIONS 9, Edition 2/1977, pages 109-120

(2) M. Arnoldt: Erzeugung von Spektrumdarstellungen im UKW-Bereich Funkschau 1977, Edition 11, page 489

(3) Dr. Ing. W. Schmitz: Spektrum-Analysatoren Elektronik-Industrie, Edition 12/1979, and 1/1980

Eugen Berberich, DL 8 ZX

A Spectrum Analyzer for VHF/UHF Amateurs

Part 2: PC-Board for the Premixer Module

In Edition 4/1980 of VHF COMMUNICATIONS, the author described a spectrum analyzer for home construction for the three frequency ranges of: 1 – 400 MHz, 430 – 800 MHz, and 1230 – 1600 MHz. A so-called premixer was required for the lowest and highest frequency ranges. The position of the components in this module is rather critical if the cross-talk between the channels is to be kept low. The author informed us in the original article that he would describe a proved PC-board for the premixer module. In addition to this, further details are to be given regarding a 39 MHz helical filter with Q-multiplier for the intermediate frequency of the spectrum analyzer.

1. CIRCUIT OF THE PREMIXER

The circuit diagram given in Figure 7 of the original article was further improved in the development of the final version which is shown in **Figure 1.**

Switching diodes type BA 182 (or BA 283) are used for switching the frequency ranges. The high-pass filter for frequency range III (1230 – 1600 MHz) comprises printed inductances (L 5 and L 6) and three ceramic capacitors (C 1 – C 3). The Schottky ring mixer type SAM-5 (Mini-Circuits) requires an oscillator power of 7 dBm (5 mW). According to the data sheet, the input frequency range is from 5 to 1500 MHz. According to this, the premixer will not operate optimumly in the last 100 MHz of range III. The attenuator link comprising resistors R 5, R 6 and R 7 provides a wideband, ohmic termination at the output of the ring mixer (pins 3 and 4). It is not necessary to procure exotic resistance values in order to achieve an exact 3.0 dB attenuation; when using the given values, a good matching is obtained with 3.15 dB. Finally, it should be mentioned that the values of both chokes RFC 1 and RFC 2 are not critical.

2. CONSTRUCTION

PC-board DL 8 ZX 004 was developed for the premixer. The dimensions are 35 mm × 70 mm, and it is double-coated, (see **Fig. 2**). The component side of the board is in the form of a continuous ground surface, which is only broken around the connection leads of the components that are not grounded, with the aid of a drill. The module must be completely screened by mounting it in a conventional metal box.

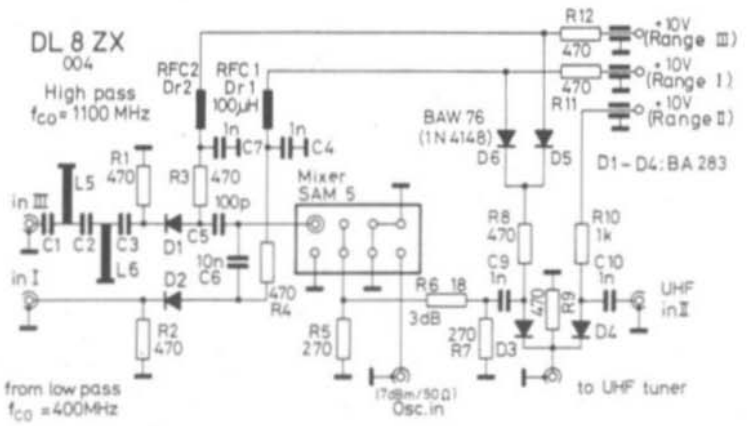

Fig. 1:
The premixer module has three measuring inputs. Two of these are converted with the aid of a wideband ring mixer, the third can be directly connected to the tuner without conversion.

Three feedthrough capacitors and five miniature coaxial connectors are installed in the side panels. If required, it is possible for coaxial cable to be directly soldered to the PC-board and to be passed through the side-panel of the box using tubular rivets.

3. A HELICAL FILTER FOR 39 MHz WITH Q-MULTIPLIER

A 39 MHz IF-preamplifier was shown in Figure 12 of the original publication. The helical filter with Q-multiplier is now to be described to allow this amplifier to be realized.

Figure 3 shows a two-stage bandpass filter made from so-called helical circuits whose high Q is to be increased further using a Q-multiplier. It is equipped with the high-power FET P 8000 (P 8002). The circuit diagram shows the transistor and other parts outside of the main circuit for clarity; however, the transistor, three chokes, ferrite bead, as well as the bypass capacitors and resistor are actually installed within the two-chamber box. One feedthrough capacitor, each, connects the circuit to the operating voltage and to the potentiometer for adjustment of the Q-multiplier.

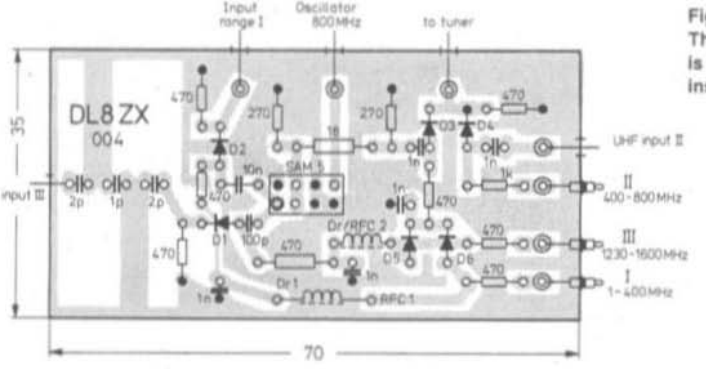

Fig. 2:
The PC-board of the premixer is double-coated and is installed in a metal case.

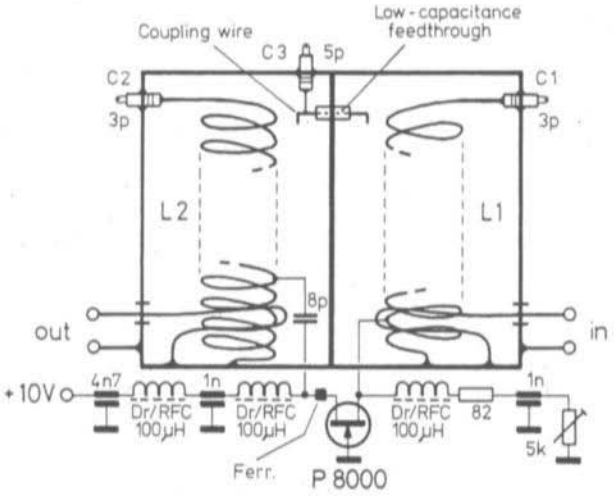

Fig. 3:
Two-stage helical filter with Q-multiplier for the 39 MHz IF.

The helical bandpass filter is designed for installation in two metal-plate cases whose dimensions are 74 x 111 x 50 mm (dimensions of the cover). The inductances are constructed as follows:

L 1: 21 turns of silver-plated copper wire of 1.5 mm dia., wound on a 25 mm former, self-supporting, coil tap: 1 turn from the cold end.

L 2: As L 1, but coil tap at 4 turns from the cold end.
Input and output coupling: one turn, each, of insulated wire at the cold end of L 1, or L 2.

In order to avoid any microphonic-type effects due to shock, the two coils should be supported by PTFE-supports or strips at the center.

The inductances are pulled out to approximately 3/4 of the length of the case, and brought to resonance by adjusting the ceramic tubular trimmers C 1 and C 2. A coupling wire is provided between the hot (capacitive) ends of the coils. Trimmer C 3 extends the wire to form a capacitive voltage divider which allows the coupling to be varied.

A compromise must be found between the slope of the passband curve and stability. Since all adjustments affect each other, a swept-frequency system can only be avoided if one has considerable experience in this type of adjustment. The alignment is carried out after all other modules are operating correctly. The alignment is made by connecting an input signal and aligning the module according to the indication on the oscilloscope.

The editors and staff of VHF COMMUNICATIONS would like to wish all readers a happy and prosperous New Year.

We are sorry that you have received this edition too late, but this was caused by the unfortunate death of our printer, Mr. Gert Reichenbach, who fell sick and died whilst preparing this edition.